Pulsed Magnets for Energy Efficient Transport Channels

EUCARD 2 annual meeting 2015

23.4.2015

Peter Spiller

Application of Pulsed Magnets

No need for c.w. operation of e.g. n.c. beam transport magnets if the beam pulse length is in the order of e.g. < 1 μs and the repetition frequency is low

Transport of bunched ion or electron beams e.g.

- inbetween circular accelerators (synchrotrons, storage rings etc.)
- final focusing of bunched beams

In circular accelerators for short term applications e.g.

- controlled short term linear coupling during multi turn injection processes

Advantages of Pulsed Magnets

- Energy efficient (field is only on during flight time of ion bunch through lense)
  Low average energy consumption

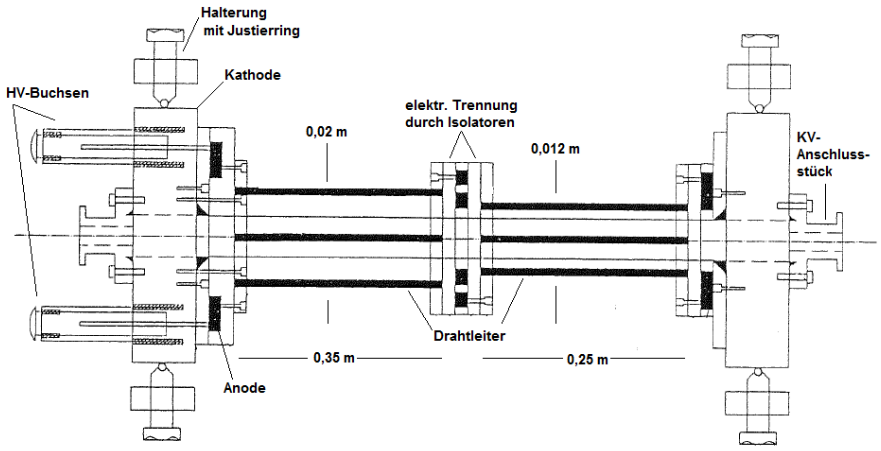
- Low heat release into air or water
  Relaxed technical infrastructure for building (water recooler, air ventilation)

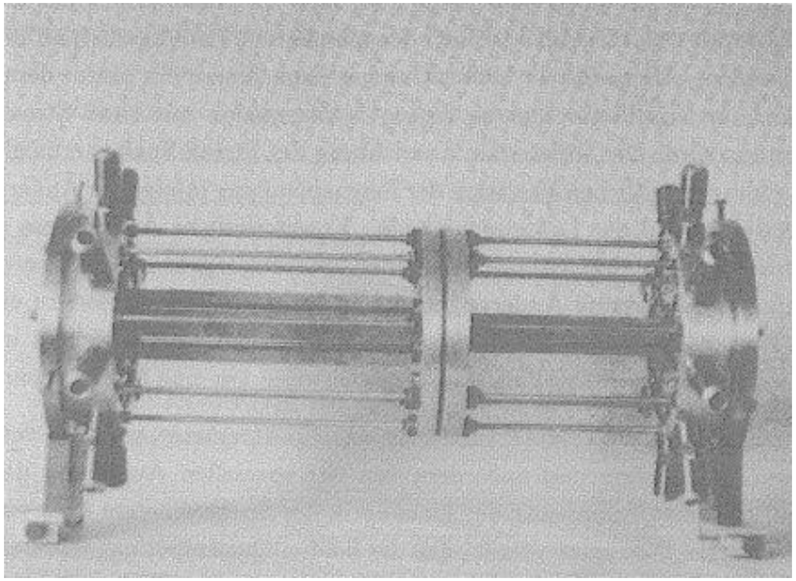
- Potential for very high fields and gradients
  Replacement for superconducting magnets with much less infrastructure effort (cryogenic plant, He distribution system etc.)

Qualitative Comparison of Different Technologies

	Conventional Magnets	Superconducting Magnets	Plasma- or Lithium Lenses	High Current Pulsed Magnets
Degree of maturity	High	High	Moderate	Low
Operation	Quasi static	Quasi static	Pulsed	Pulsed
Aperture	High	Limited	Limited	Limited
Space requirememts	High	Highe	Moderate	Low
Field strength/gradients	Limited	High	High	High
Average energy dissipation	High	Low	Low	Low
Electromagnt. stray field	Low	Low	High	Moderate
Technological complexity	Low	High	High	Low
Cost	Low	High	Moderate	Low
Reliability	High	High	Moderate	Moderate
Beam shape	bunched/cw	bunched/cw	Bunched	bunched

History at GSI





Prototype Quadrupole Magnet

Prototyping is in the responsibility of the Group „High Voltage Pulse Power“

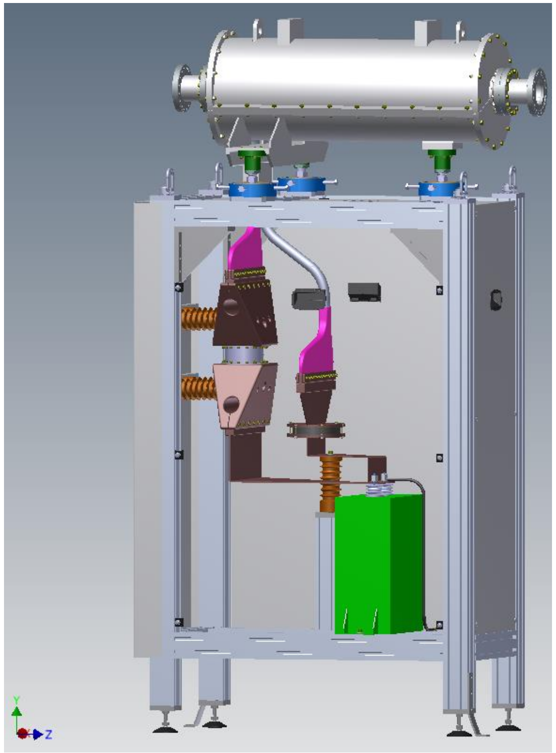
- GSI plans to build a prototype high current pulsed quadrupole magnet for a final focusing for SIS18 beams
- Engineering pre-design has been completed
- EUCARD deliverable 3.2. „Design study“ has been achieved.
- Tendering for the manufacturing of the prototype lens completed.

Potential Technologies

Switch type
Pseudospark switch (used)
Spark gap
Ignitron
Semi conductors
Evtl. Thyratrons
Energy storage
Capacitors
Pulse cable
PFN

Prototype Quadrupole Magnet – Technical Parameters

	Prototype Quadrupole
Gradient	80 T/m
Length	0.65 m
Pulse length	90 μs
Peak current	400 kA (35 kA)
Peak voltage	17 kV (5 kV)
Energy @17 kV	65 kJ (5.6 kJ)
Inductivity	535 nH
Capacitor	450 μF
Forces	200 kN



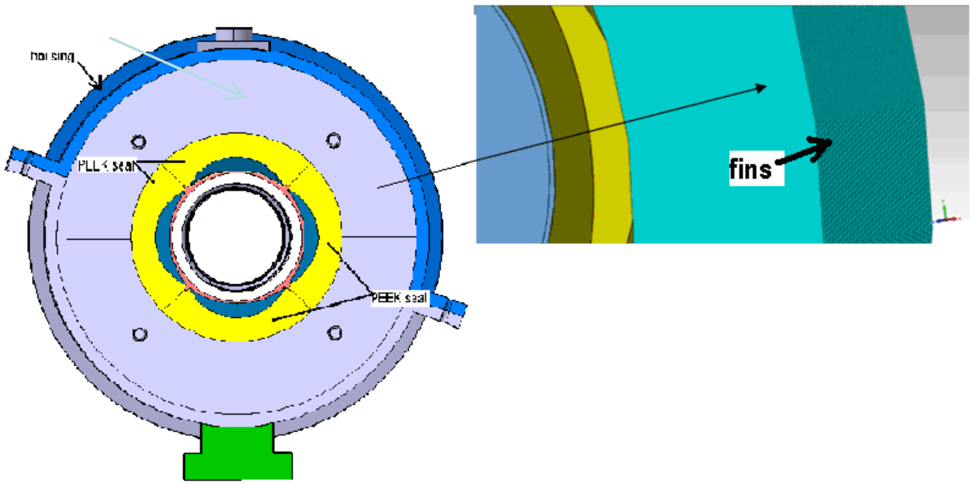
Engineering model of the prototype quadrupole magnet incl. support

Comparison Pulsed Quadrupole – Conventional Quadrupole

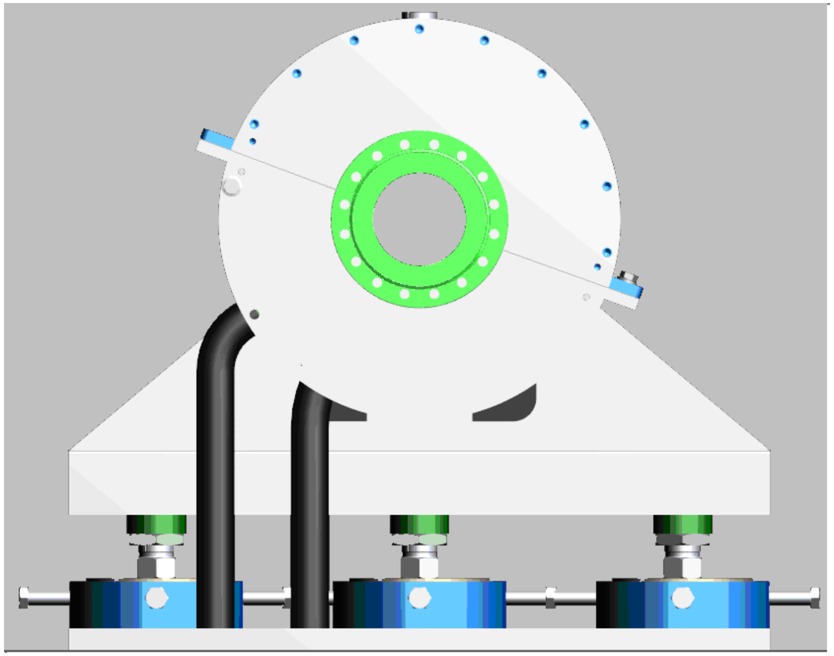
	Conventional Quadrupole	Pulsed Quadrupole
Gradient	10 T/m	15.38 T/m
Length	1 m	0.65 m
G x L	10 T	10 T
Apertur radius	0.065 m	0.056 m
Peak current	270 A	77 kA
Peak voltage		4.7 kV
Stored energy	5,5 kJ (in magnet gap)	5 kJ (in capacitor)
	SIS18 repetition rate: 1 Hz	
Power	18 kW	5 kW

Detailed investigation of energy efficiency for transport channels: P. Gardlowski

Prototype Quadrupole Magnet – Cross Section

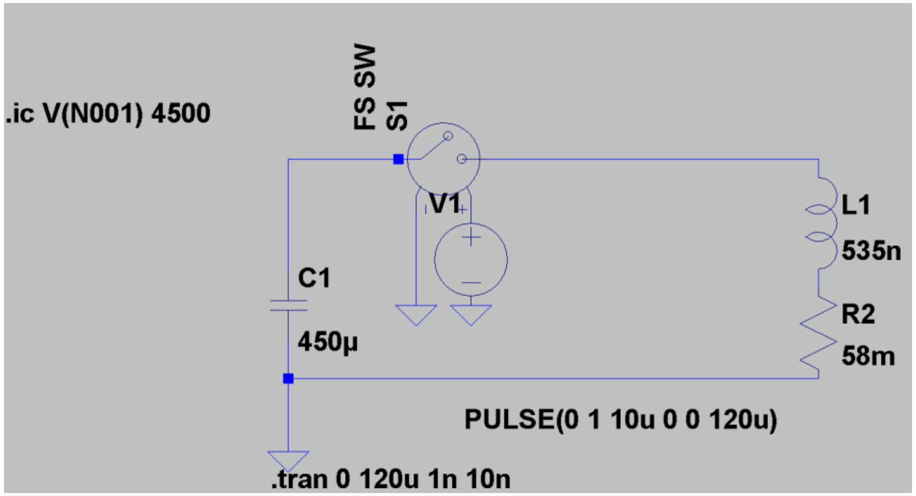


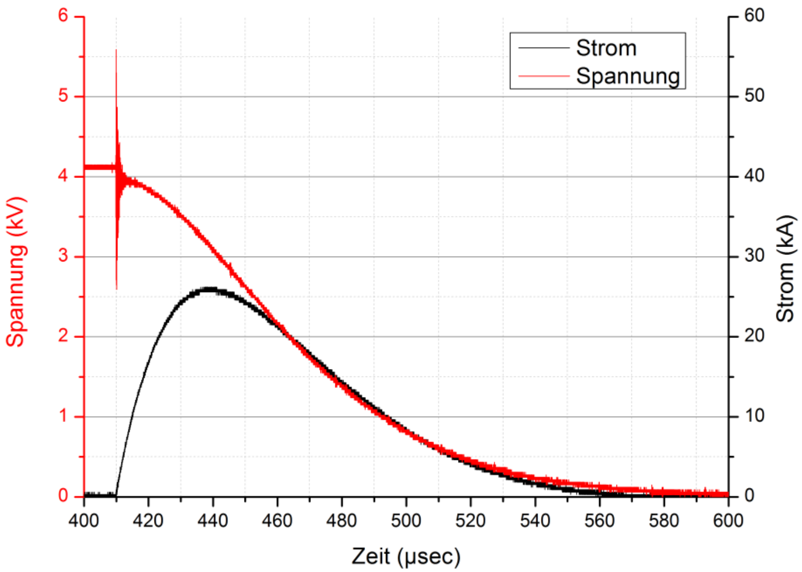
Cross section of the pulsed quadrupole magnet with
- stainless steel collar
- laminated yoke
- peek spacers
- coil
- ceramics beam pipe



Connection side of the lense

Electrical Circuit



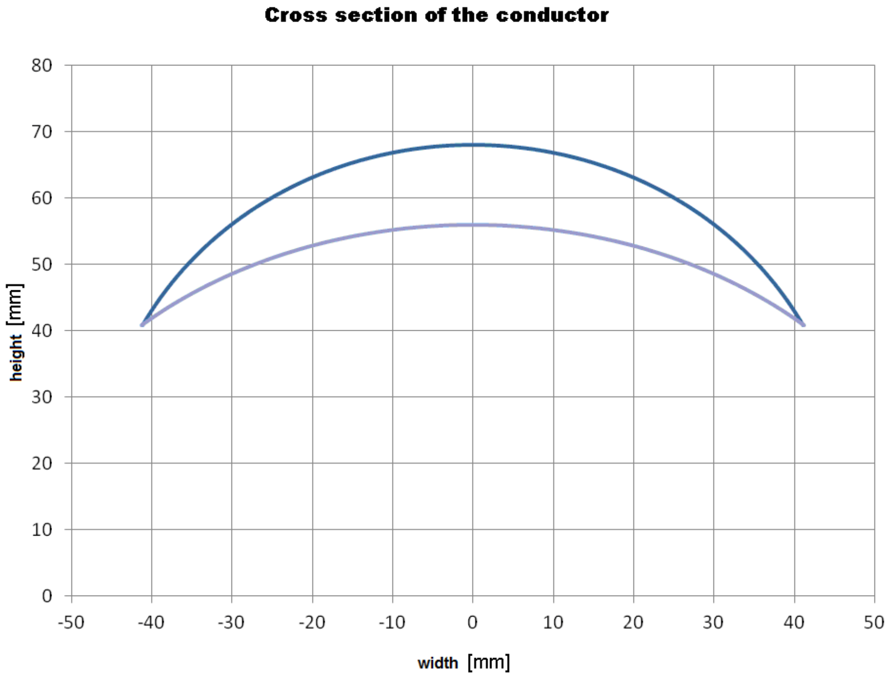


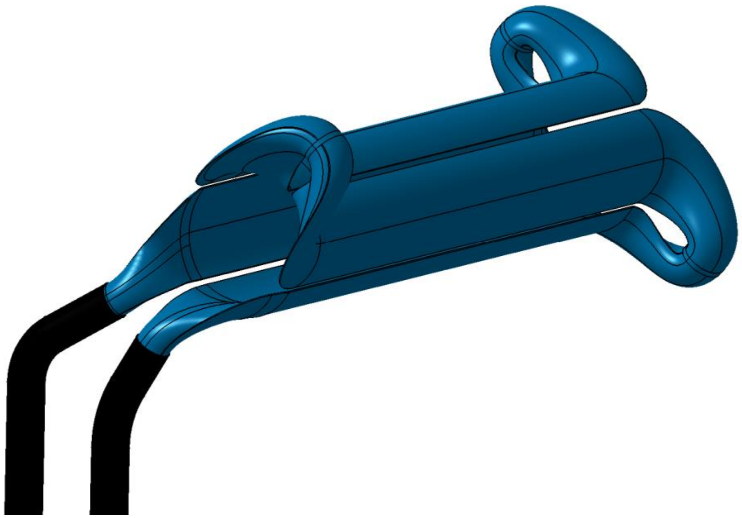
Equivalent electrical circuit

Measured voltage and electrical current

Conductor Geometry

Has to generate a cos2theta current distribution over the cirumference similar to a superconducting magnet

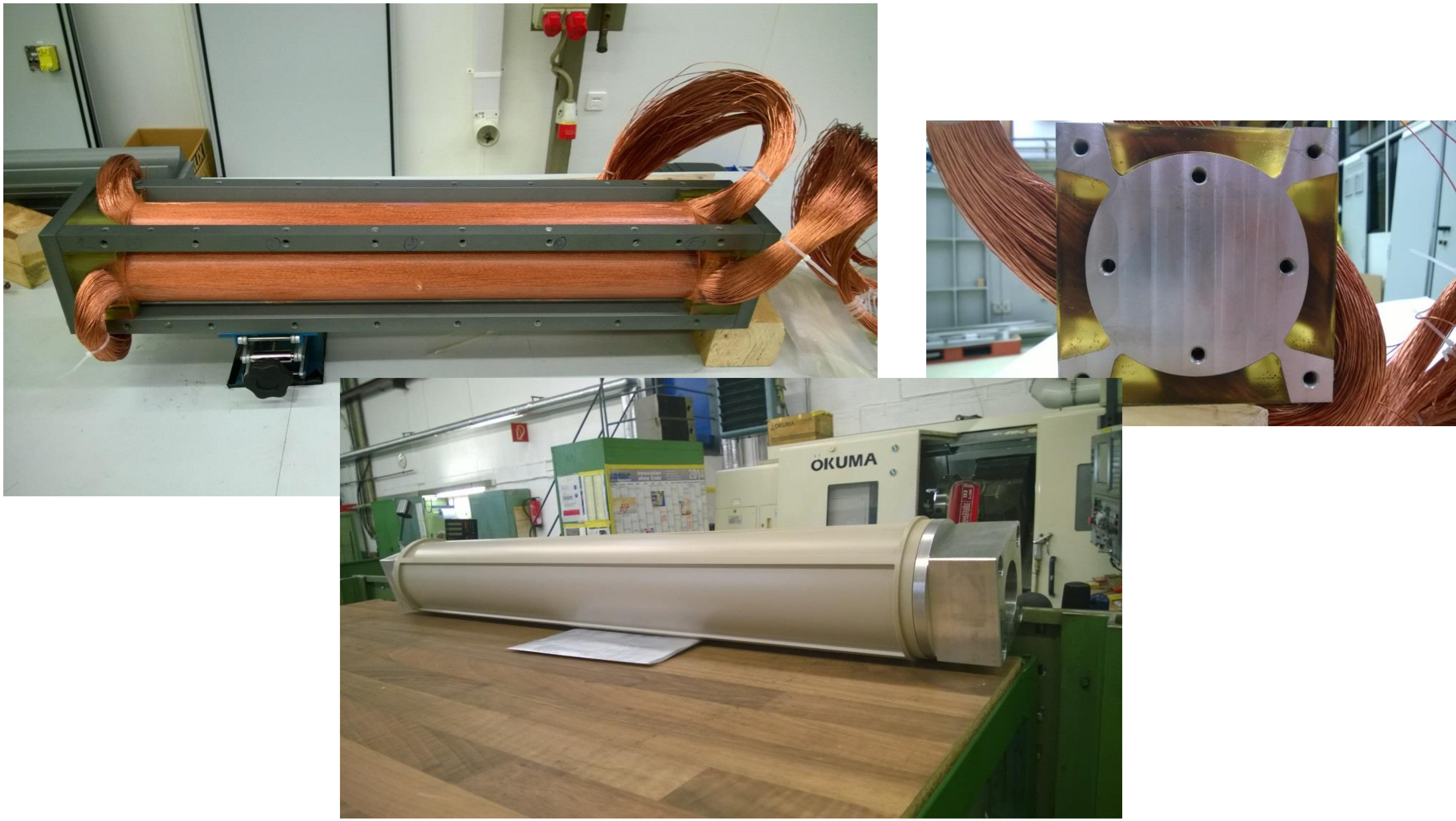




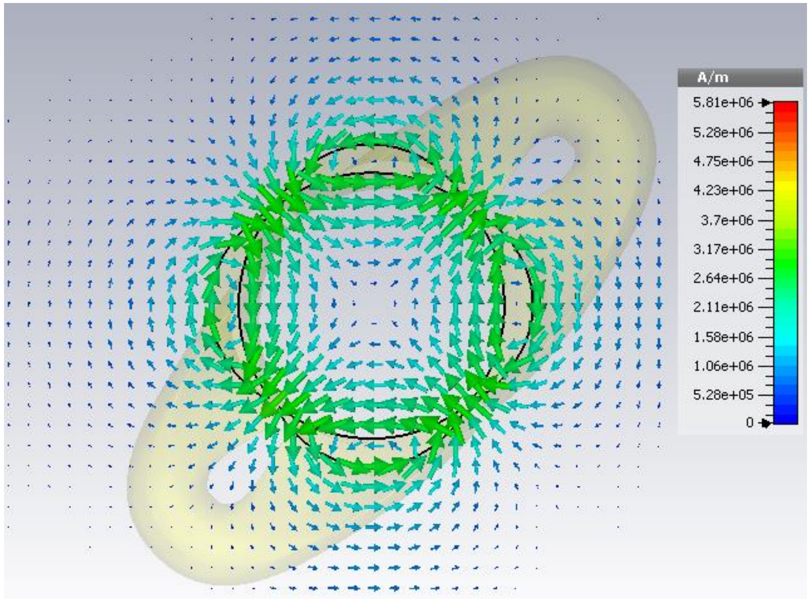
Cross section of the optimized conductor

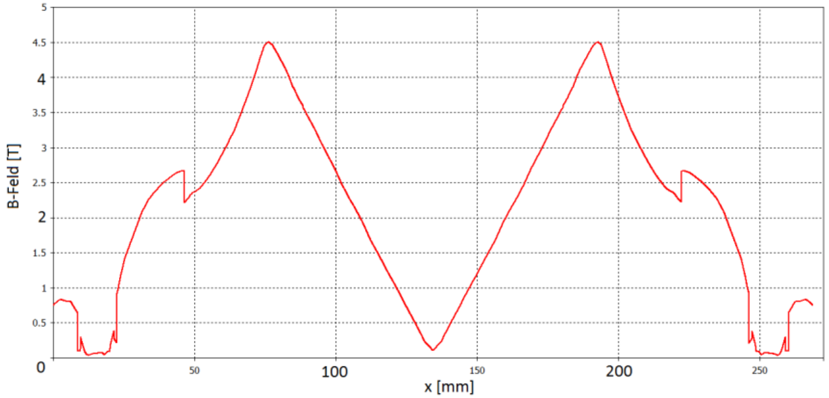
Layout of the prototype coil

Coil Production



Field Quality



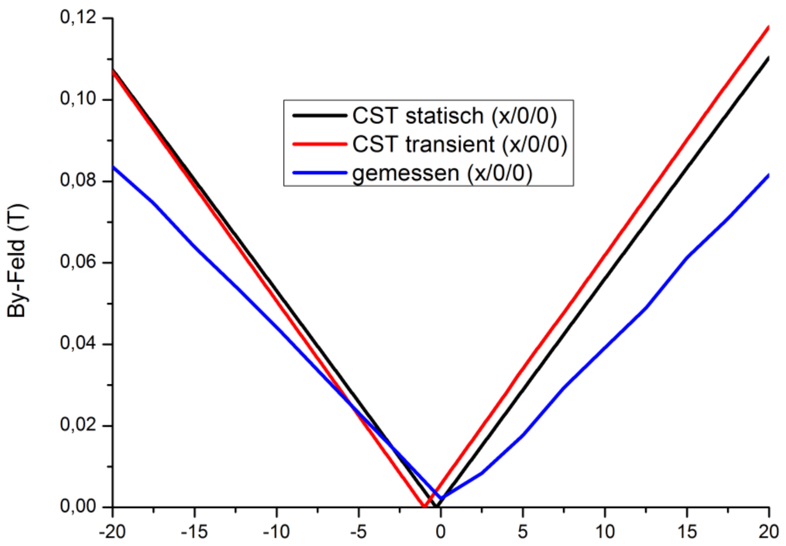


Calculated field distribution

Transient Effects

To avoid the skin effect in the conductor,
special effort has to be take to assure a homogenous current distribution in the shown conductor cross section (model has been build).

Patent in preparation

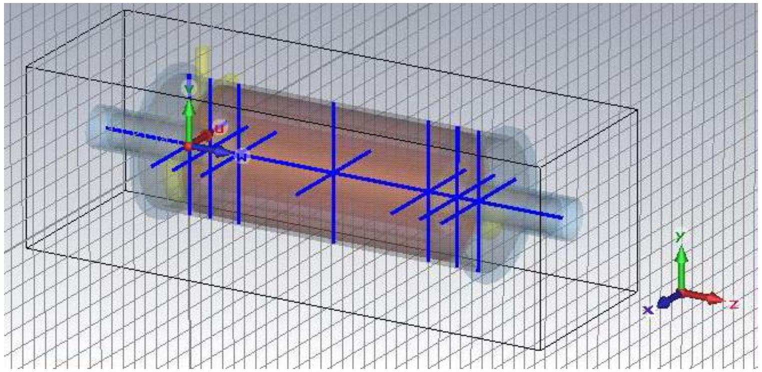


Distance from center [mm]

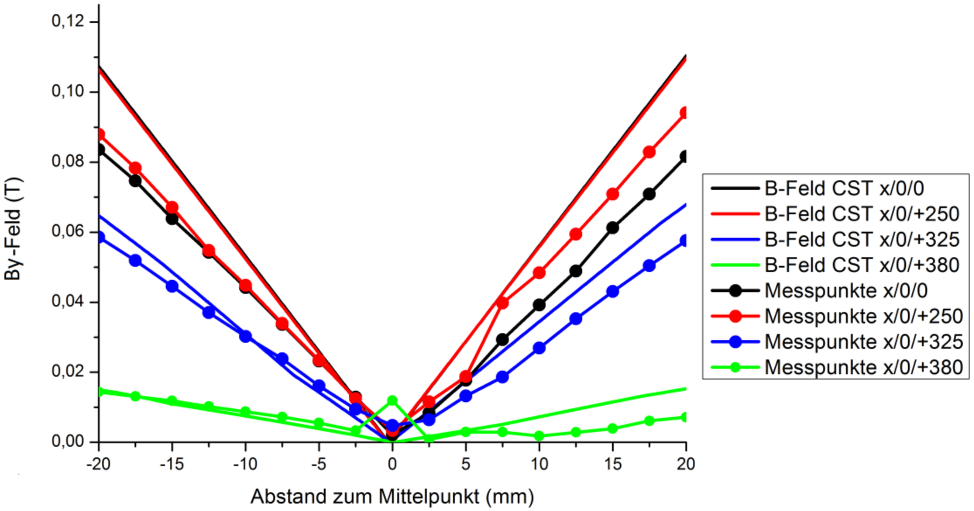
Magnetic Field Measurements in Pulsed Quadrupole

Gradient hall probe with pulsed quadrupole

Magnetic Field Measurements in Pulsed Quadrupole

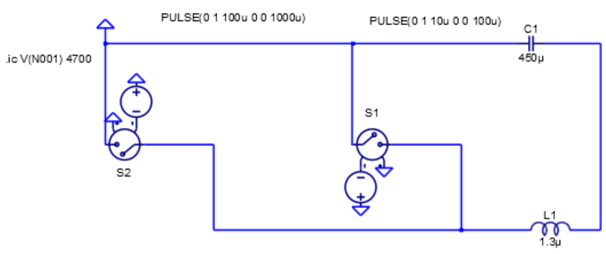


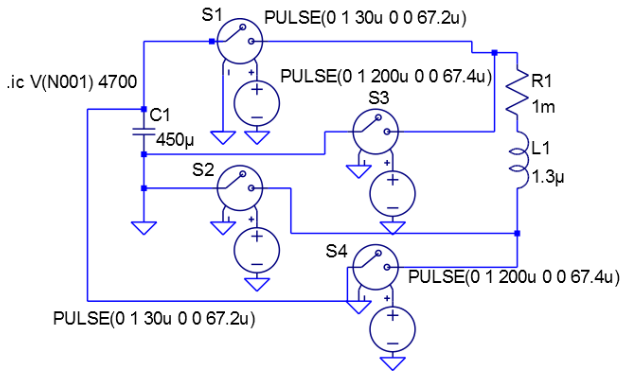
Axis along field measurements

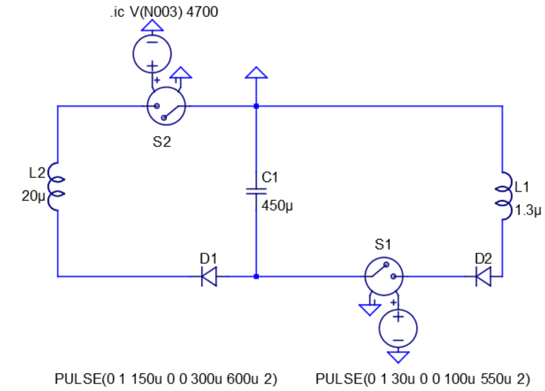


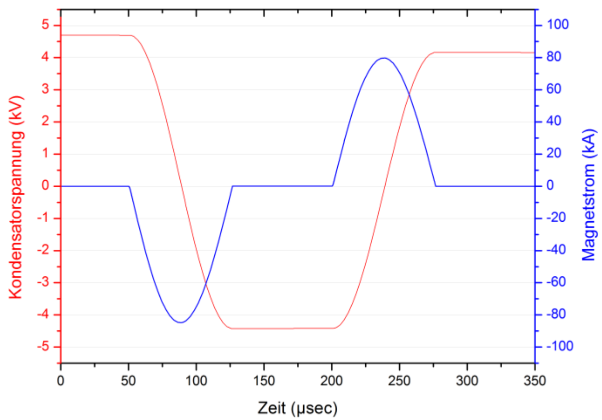
Comparison of CST simulations
with magnet field measurements

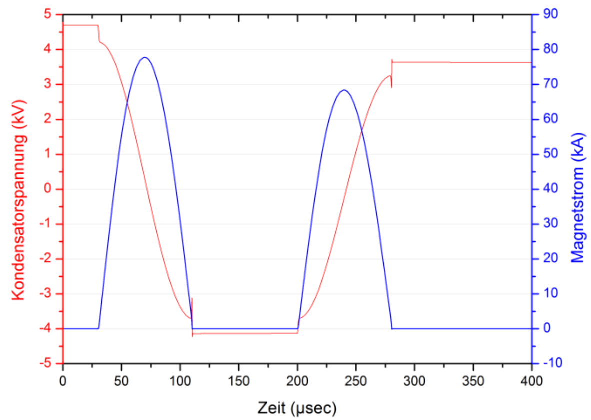
Concepts for Energy Recovery

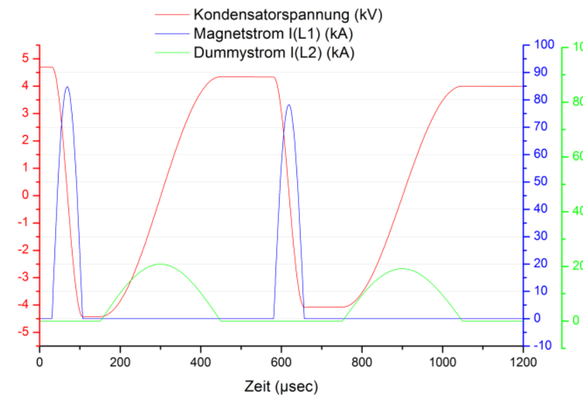












Next Steps

Prototype Project
Design, Production and Commissioning of the prototype lens completed.
PhD theses completed.

Perspectives
Production of a second lens (as quadrupole doublet) for final focusing of SIS18 beams.
Evtl. preparation of a pulsed skew quadrupole for linear coupling during MTI into SIS18.
Increased repetition frequency by adapting the design to water cooling

System Design (See talk by P. Gardlowski)
Start of a comparison of beam transport technologies from the system design point of view and with respect to energy efficiency.

Members of the Pulse Quad Development Team

- Carmen Tenholt (phd thesis)
- Udo Blell
- Isfried Petzenhauser